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EXPERIMENTAL INVESTIGATION OF WATER SUBMERGED ABRASIVE WATER JET MACHINING OF CARBON FIBRE REINFORCED PLASTIC COMPOSITES

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ABSTRACT

In the present work, effects of abrasive flow rate, stand-off distance and traverse speed has been visualised on surface roughness of CFRP composite material using water submerged Abrasive Water Jet Machining (AWJM). The experiments were conducted based on Response surface design created by MINITAB 17. Regression models were established to predict the correlation between the input process parameters and surface roughness for CFRP. This process is mainly best suited for cutting thermo- sensitive materials which cannot be machined by. It is very much suitable and economical technique to machine the various types of metals, alloys, polymers, glass fibre metal and composites etc. AWJM process is characterized by several process parameters that influences the machining quality. In this work, effect of parameters viz. traverse speed, stand-off distance and water pressure on surface quality of CFRP composites has been inspected. Response surface methodology is being adopted for experimentation. Analysis of variance (ANOVA) is applied and box bhenken design is used for three (3) factors and number of runs are fifteen (15). Comparison of results has been successfully accomplished with the existing literature. The experimental results showed that surface roughness is decreasing with a decrease in abrasive flow rate and traverse speed of AWJM. When the abrasive flow rate is less than 140 g/min and Traverse speed is in between 35 – 60 mm/min.

KEYWORDS: Abrasive Water Jet Machining (AWJM,) Carbon Fiber Reinforced Plastic (CFRP), Response Surface Design & Surface Roughness

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Original Article

INTRODUCTION

Carbon Fibre Reinforced Plastic (CFRP) composite materials are the advanced polymer composites developed for high strength to weight ratio applications/industries such as aerospace, marine, sports equipment, etc. CFRP is used for weight reduction of an aerial vehicle for improving the fuel efficiency thereby reducing the carbon emission as well as for enhancing the freight capability. It is relatively simple to analyse the material removal mechanism for conventional machining of traditional homogeneous materials. However, CFRP is made up of the non-homogeneous, anisotropic reinforced fibres which has relatively high abrasiveness and hardness. Owing to this, such composites are difficult to machine. Delamination of the fibres, reduction in fatigue strength have been the common problems associated with the machining of CFRP composites which in turn affect the durability of the product [1]. Abrasive Water Jet Machining (AWJM) is a non-traditional manufacturing process which utilises the kinetic energy of water and abrasives mixture for machining of the workpiece. Water is kept at high pressure and this entire pressure is converted into kinetic energy through a nozzle. Quality of produced intricate geometry and cutting accuracy have been some of the challenges of machining of CFRP composite through AWJM. Hence, extensive experimentation of AWJM under varied conditions of AWJM process parameters is needed [2]. Researchers have investigated parametric influence of AWJM on a wide variety of CFRP composites. Hofy et al.

[2018] has performed AWJM experiments on CFRP and observed that the machining of CFRP is cheaper as compared to other conventional type machining such as milling [2]. From the existing literature, it has been observed that regression based modelling has been the best suited approach for predictive analysis of surface roughness. Kumaran et al. [2017] noticed that the higher water pressure when combined with a slower speed and less stand of distance have been resulted in an improved surface quality [3]

Figure 1: AWJM Machining setup.

Wong MM et al [2018] revealed that stand off distance and traverse speed were the prominent parameters which influences kerf ratio of CFRP materials [4]. The authors have machined the woven prepreg composite laminates with AWJM and investigated the samples with a Computed Tomography (CT) scan and X-ray imaging techniques. The results have shown that delamination could be avoided with AWJM process [5]. Monoranu et al. (2019) have compared the flexural strength of CFRP composites when machined with conventional milling and AWJM. Optical and scanning electron microscopy methods along with high speed digital image correlation techniques have been applied and results have shown that AWJM have produced the parts with better flexural strength [6]. Haghbin et al. (2015) have compared the micro-milling of two steel alloy and aluminium alloy with submerged and unsubmerged AWJM process. It was observed that the channel width when machined in air was broader than that in water submerged AWJM and later results in narrower micro slots than unsubmerged AWJM without decreasing the etch rate at the centre line [7]. Narkhede and James (2018) have experimentally investigated the precision machining of hybrid CFRP composites stack with submerged AWJM and concluded that submerged AWJM process has resulted in higher precision machining as compared with unsubmerged AWJM [8]. James and Narkhede (2019) has performed precision submerged AWJM experiments with titanium and CFRP hybrid composites stacks and further build the analytical model for predicting the material removal rate [9]. Gulia and Nargundkar, (2019) have optimised process parameters of AWJM using contemporary socio inspired optimization technique referred to as cohort intelligence technique [10].

2. EXPERIMENTATION

2.1 Material and Experimental Setup

CFRP composite is an exceptionally robust and nimble fibre-reinforced plastic, which comprise of carbon fibres. CFRP has its application wherever high specific strength and rigidity are required, viz, aerospace, super structure of ships, automobile sector, structural engineering, sports industry etc. For the current work, rectangular plate of 5 mm thick CFRP substrate

was considered. Experimentation were performed to form the slots of 1.5 mm width size. The Experiments were performed using AWJM machine which is integrated with high operating pressure pump as shown in Figure 1. The nozzle diameter and orifice diameter were 0.7 mm and 0.35 mm, respectively. 80 mesh size (approximately 180 microns) garnet abrasive particles has been employed with the pressurised water. In this work, the abrasive flow rate is kept constant between 100 – 200 g/min owing to see the effect of other parameters.

2.2 Design of Experiment

Several process parameters affect the AWJM process quality. However, literature suggests that Traverse Speed (TS), Abrasive Flow Rate (AFR) and Stand-Off Distance (SOD) are vital process parameters which effect on surface roughness was selected as process response because product quality has been indicated by the considered responses. Upper and lower limits of parameters have been selected based on literature review and trial and error method. Response Surface Methodology (RSM) have been adopted for designing the experiments because of its advantages such as easy smoothening of Noise, axial points were utilized for the formulation of the table because it gives the data well within the bounds of parameters, easy statically analysis. MINITAB 17 platform has been used. Three levels of TS, SOD and AFR as shown in table 1 are selected. Table 2 shows the combination of parameters generated with RSM which were used for experimentation.

Table 1: Level of Parameters

Process Parameters	Level 0	Level 1	Level 2
Nozzle transverse speed(mm/min)	30	55	80
Stand of distance (SOD) in mm	1	3	5
Abrasive flow rate (g/min)	100	150	200

Table 2: Experimental Table

Run Order	TS (mm/min)	SOD (mm)	AFR (g/min)
1	80	3	200
2	55	3	150
3	55	1	100
4	30	1	150
5	30	5	150
6	30	3	200
7	55	5	100
8	55	3	150
9	80	1	150
10	55	3	150
11	30	3	100
12	55	1	200
13	55	5	200
14	80	3	100
15	80	5	150

2.3 Experimentation

Three levels each of TS (30, 55, and 80 mm/min) and SOD (1, 3, and 5 mm) were selected. Mitutoyo SJ-210 profilometer were used to measure two-dimensional (2D) roughness profile. For the measurement of surface roughness, the cut off length considered was 4 mm and the stylus of the profilometer was inserted in the cut slot of the machined specimen. Fig.2 shows AWJM machined specimen.

Figure 2: Abrasive Water Jet Machined CFRP Material.

3 RESULTS

The performance of Machining is majorly dependent on the Surface Quality of the specimen. As the surface roughness (Ra) plays an important role in tribology, rough surfaces wear quicker than smooth surfaces due to more friction coefficient. These irregularities provide nucleation sites for cracks or corrosion and may promote adhesion. It also has influence over maintaining close tolerances. Therefore, it is very important for a machining process to provide good surface finish with least value of Ra. Table 3 represents surface roughness response.

Table 3: Experimental Table with Response Ra

Run Order	TS (mm/min)	SOD (mm)	AFR (g/min)	Ra (µm)
1	80	3	200	3.98
2	55	3	150	3.26
3	55	1	100	3.41
4	30	1	150	3.06
5	30	5	150	3.24
6	30	3	200	3.21
7	55	5	100	3.22
8	55	3	150	3.26
9	80	1	150	3.89
10	55	3	150	3.26
11	30	3	100	3.11
12	55	1	200	3.42
13	55	5	200	3.23
14	80	3	100	3.88
15	80	5	150	4.136

3.1 Effect of SOD and TS on Surface roughness (Ra)

Figure 3 shows the contour plot of Ra as a function of the input process parameters TS, and SOD.

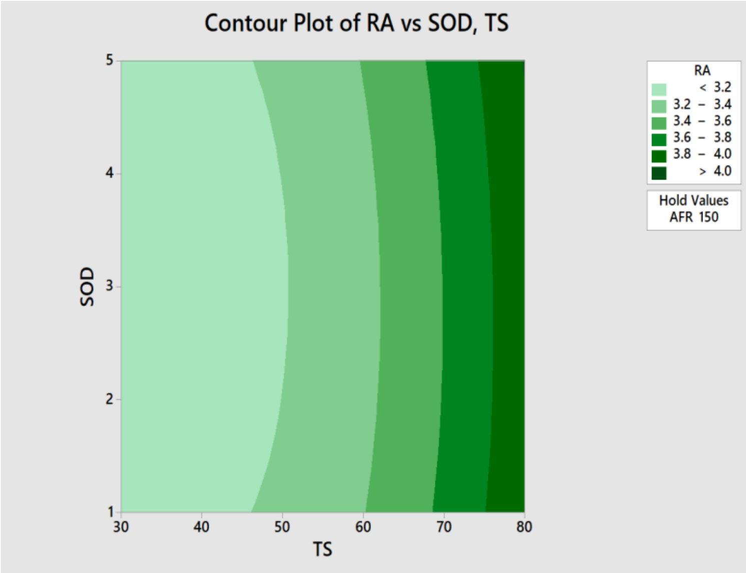

Figure 3: Contour Plot of Ra vs SOD, TS.

It was found that minimum Traverse speed and minimum SOD produced lower surface roughness in CFRP.

The excerpt from Minitab platform for regression modelling, analysis of variance for Ra is shown in fig.6. The R-square value 94.17 % shows a good fit between process parameters TS, AFR and SOD and surface roughness.

Figure 4 shows that main effect plot of surface roughness with AFR, it implies that, as Abrasive Flow Rate (AFR) increases, surface roughness also increases.

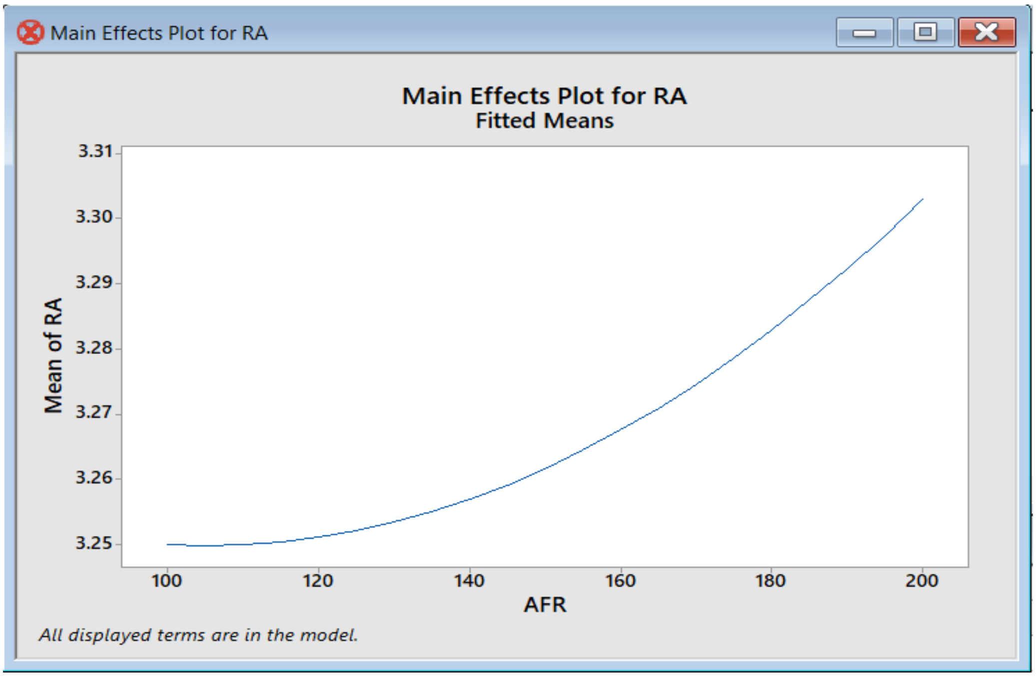

Figure 4: Contour Plot of Ra vs SOD, TS.

3.2 Effect of TS and AFR on Surface Roughness (Ra)

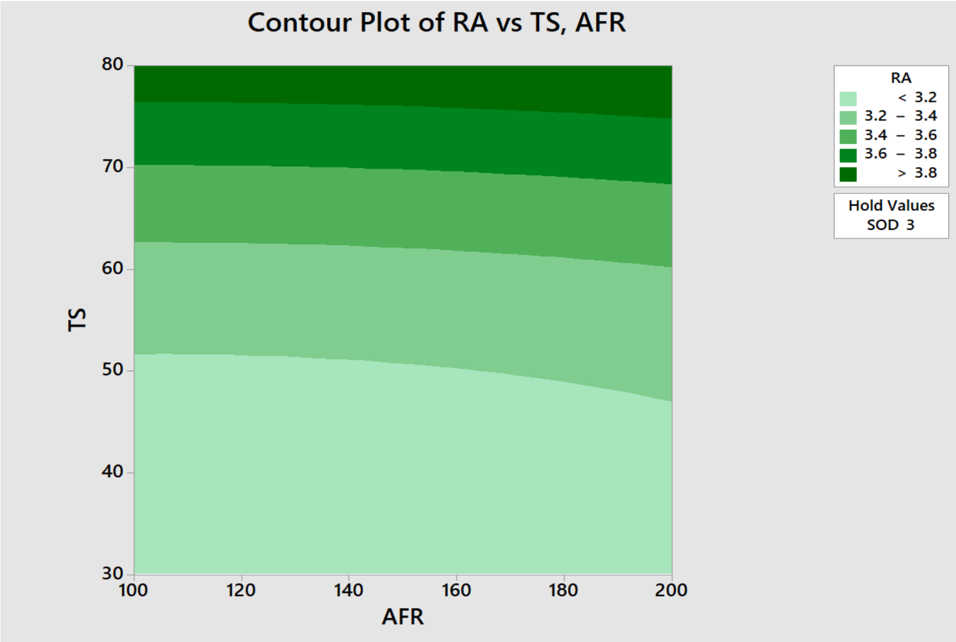

Figure 5: Contour Plot of Ra vs AFR, TS

Figure 5 shows the contour plot of Ra as a function of the input process parameters TS, and AFR. With the decrement of abrasive flow rate and traverse speed, surface quality increases.

Response Surface Regression: RA versus TS, SOD, AFR

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1.62304	0.18034	9.96	0.010
Linear	3	1.34237	0.44746	24.71	0.002
TS	1	1.33661	1.33661	73.81	0.000
SOD	1	0.00014	0.00014	0.01	0.932
AFR	1	0.00562	0.00562	0.31	0.602
Square	3	0.27979	0.09326	5.15	0.055
TS*TS	1	0.27678	0.27678	15.28	0.011
SOD*SOD	1	0.00861	0.00861	0.48	0.521
AFR*AFR	1	0.00081	0.00081	0.04	0.841
2-Way Interaction	3	0.00087	0.00029	0.02	0.997
TS*SOD	1	0.00087	0.00087	0.05	0.835
TS*AFR	1	0.00000	0.00000	0.00	0.997
SOD*AFR	1	0.00000	0.00000	0.00	0.992
Error	5	0.09054	0.01811		
Lack-of-Fit	3	0.09054	0.03018	22634.63	0.000
Pure Error	2	0.00000	0.00000		
Total	14	1.71358			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.134567	94.72%	85.21%	15.46%

Figure 6: Response Surface Regression for Ra.

4. CONCLUSIONS

Regression analysis has been performed to evaluate the various interactions amongst the input process parameters of AWJM on Ra and the following observations were made:

- It has been observed that Surface quality increases with a decrease in abrasive flow rate and traverse speed of AWJM.
- For better surface finish, high range of water pressure, low traverse speed and small stand-off distance were suggested.
- AWJM machining have been performed and submerged into the water, meaning that work piece (CFRP sheet) is submerged in water upto some extent. It is observed that surface quality has improved in case of water submerge as compared to unsubmerged AWJM.

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